Strategy to realize the EUV-FEL high power light source - Present status on the EUV-FEL R&D activities -

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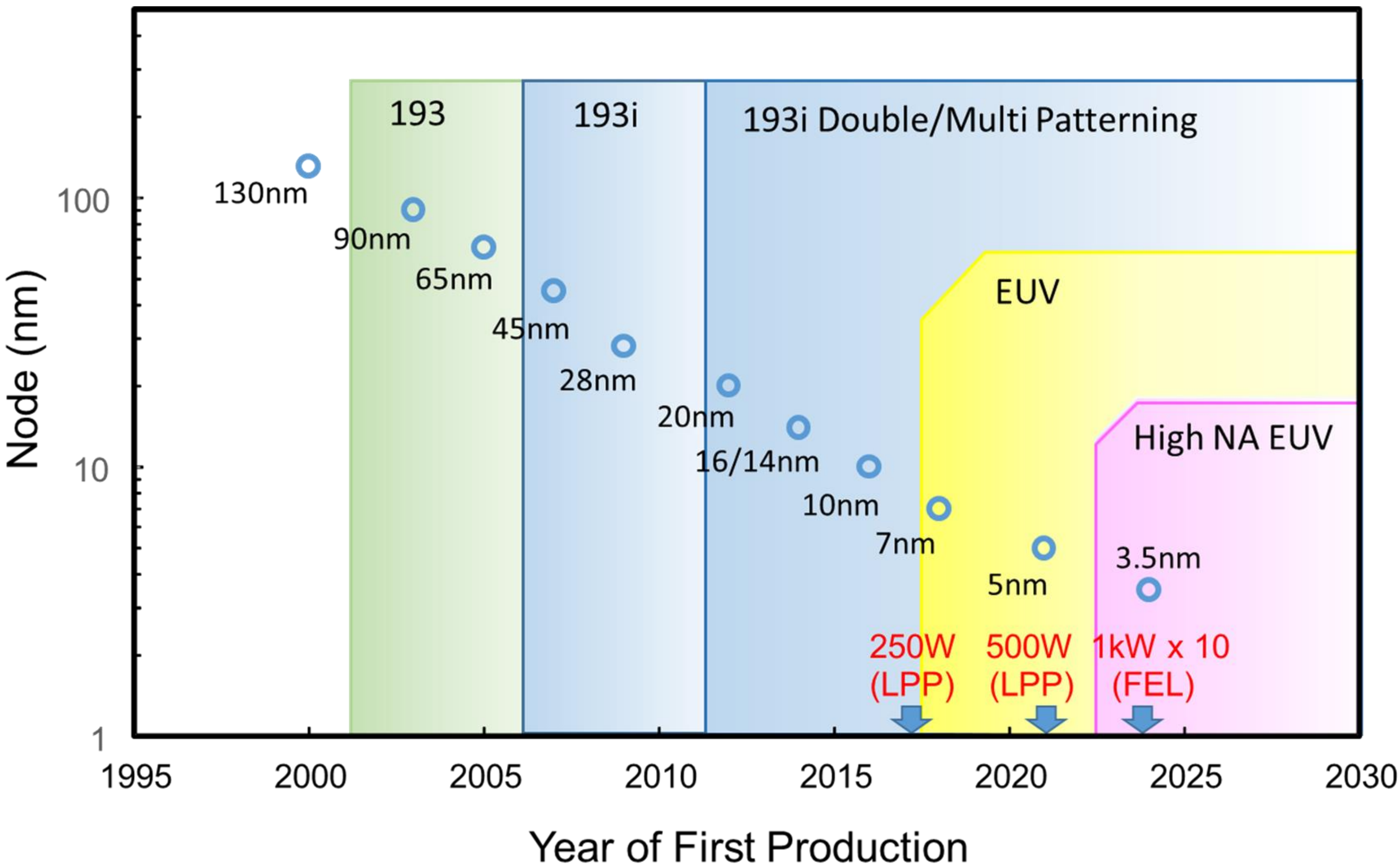
Technology node trend of Logic LSI and expected power on EUV light source



Present Status and Future Development on EUV Lithography (1)

Present Status

- The technologies on EUV Lithography system based on LPP light source are progressing, now.
- The system based on ~200 W LPP light source is starting point of the production phase.

Future Development

- It is expected that these on ~1kW source will be necessary to realize the production less than 5nm node, too.
- It is important to develop new type light source to realize higher power than ~1kW, and also the other technologies which are related on EUV lithography such as multi-layer-mirrors, masks, and resist materials, and so on.

Design study on high power EUV-FEL light source

<u>Design concept</u>

- High energy accelerator technologies bring us 10 kW class high power EUV light source based on Free Electron Laser (FEL).

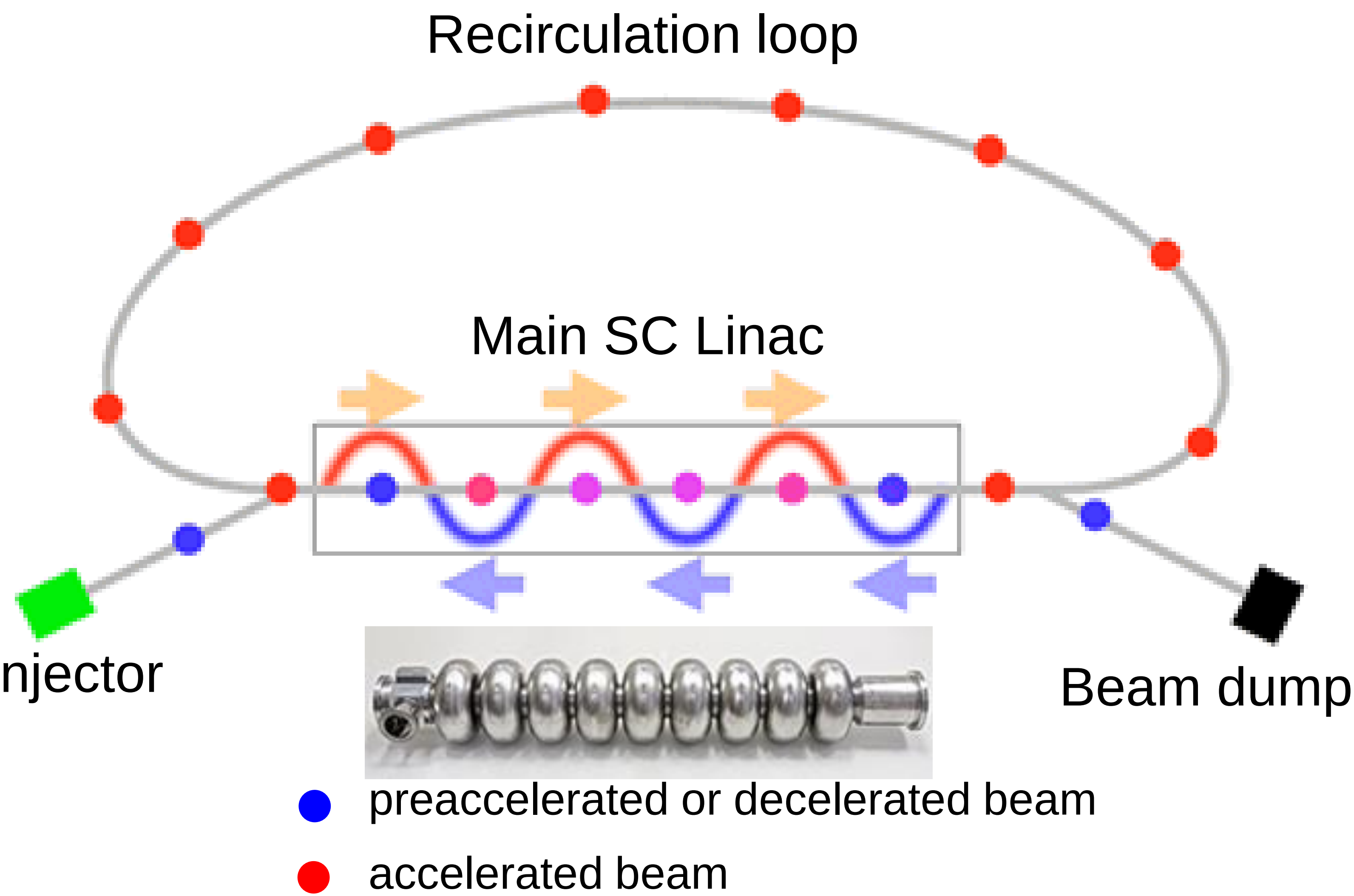
<u>Key technologies</u>

- Super conducting accelerator technologies with Energy Recovery Linac (ERL) (800MeV, 20 mA)
- High power FEL technologies (~30 kW)
- Accelerator elements, systems and operation skill, which are developed in cERL at KEK

Rough estimation of the FEL radiation power

	LCLS	SACLA	FLASH	Euro-XFEL	LCLSII	EUV-FEL
Type of linac	Normal conducting		Super conducting			
Operation mode	Pulse		Long pulse		CW	
Country	US	Japan	Germany	Germany	US	-------
ERL scheme	No	No	No	No	No	**Yes**
Repetition rate	120	30～60	<5000	<27000	1M	**162.5M**
Accelerate Energy (MeV)	14300	6000～8000	1250	17500	4000	**800** 0.01@Injection
Minimum wave length (nm)	0.15	0.08	4.2-52	0.05	~0.3	13.5
Power/pulse (mJ)	~10	~10	<0.5	~10	~1	~0.1
Power/s (W)	~1	~1	<0.6	~100	~1000	**>10000**
Beam dump power (W)	~1.5k	~0.5k	~6k	~0.5M	~1M	**~0.1M**
Operation/ Construction/ Planning	Operation 2009	Operation 2011	Operation 2004	Construction 2017	Construction 2020	Planning

Energy Recovery Linac(ERL)

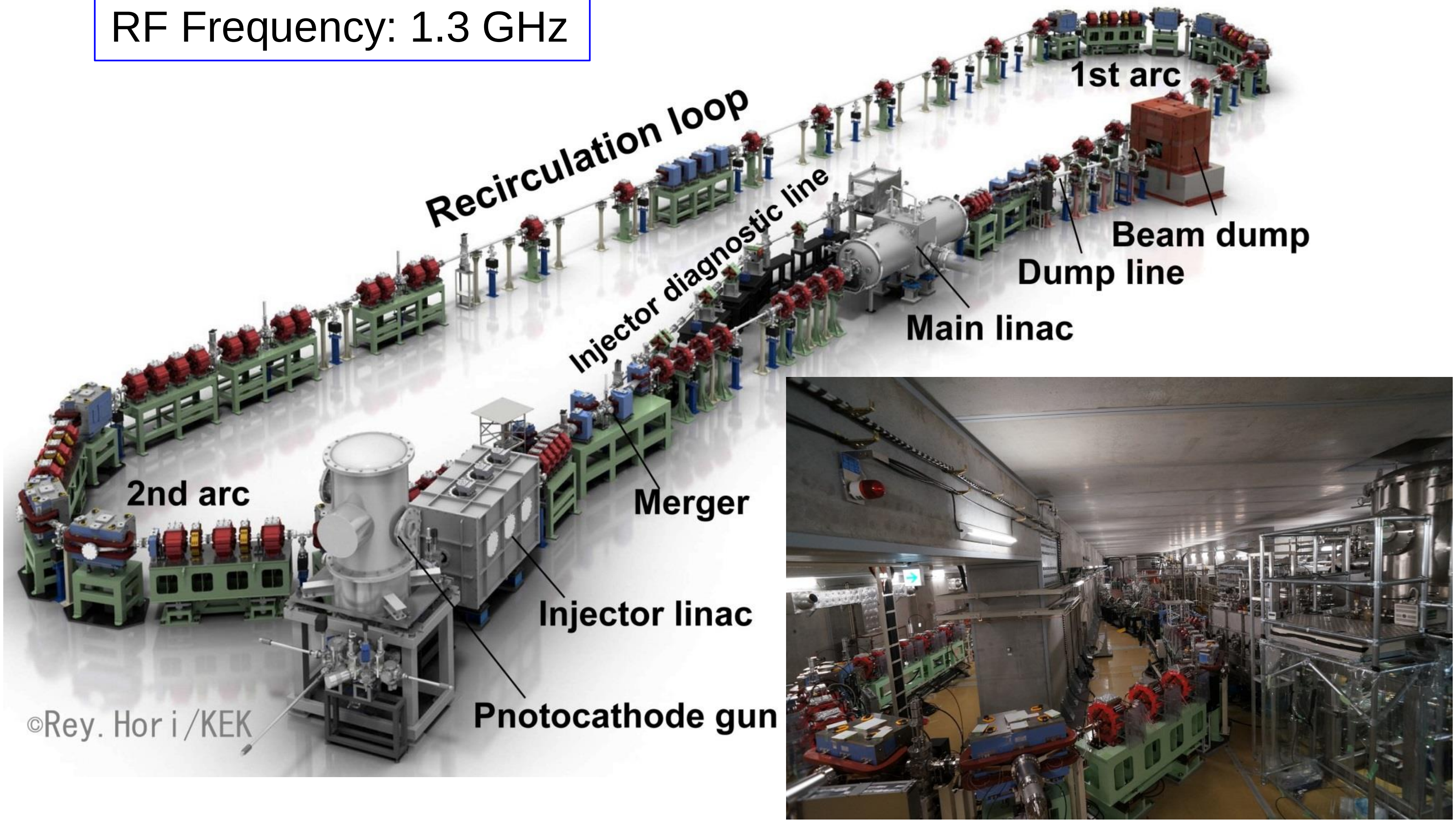


After the presentation at OSA workshop in Hiroshima (27-28/Oct.2016) presented by Prof. N. Nakamura

Compact ERL(cERL) at KEK

Beam Energy: 20 MeV
RF Frequency: 1.3 GHz

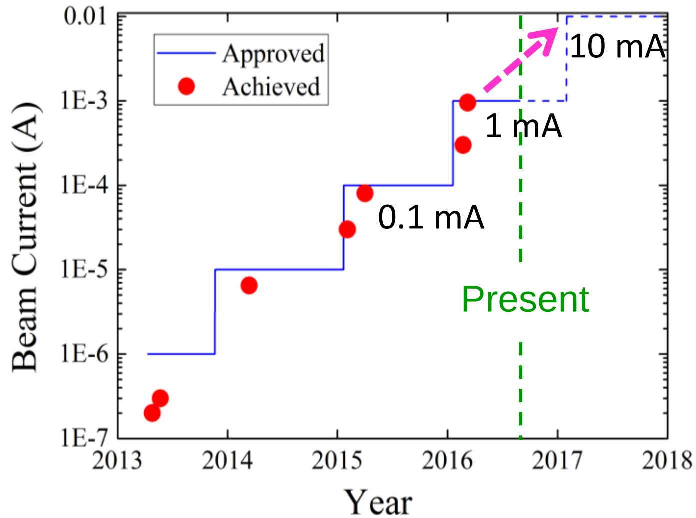
in operation since 2013



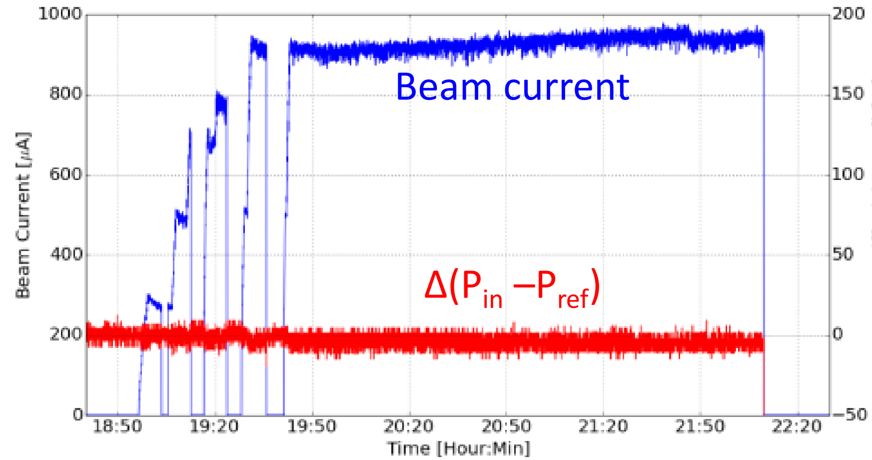
After the presentation at OSA workshop in Hiroshima (27-28/Oct.2016) presented by Prof. N. Nakamura

Recent Progress of cERL

(1) High average current

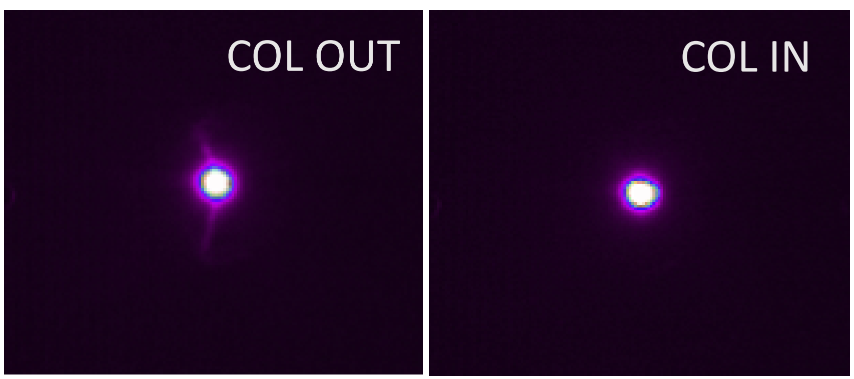


History of achieved beam current



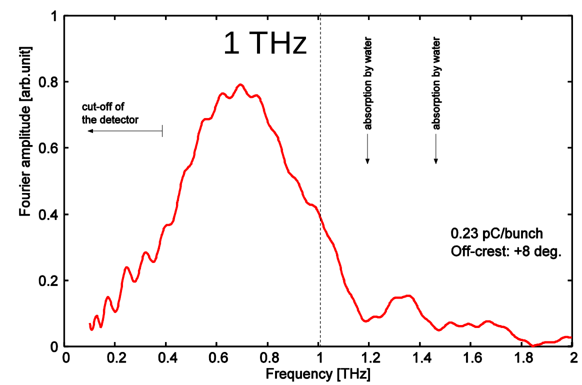
Achievement of high beam current (~1 mA)
with efficient energy recovery (~99.97 %)

(2) Beam loss reduction



Mitigation of beam halo by collimators at injector

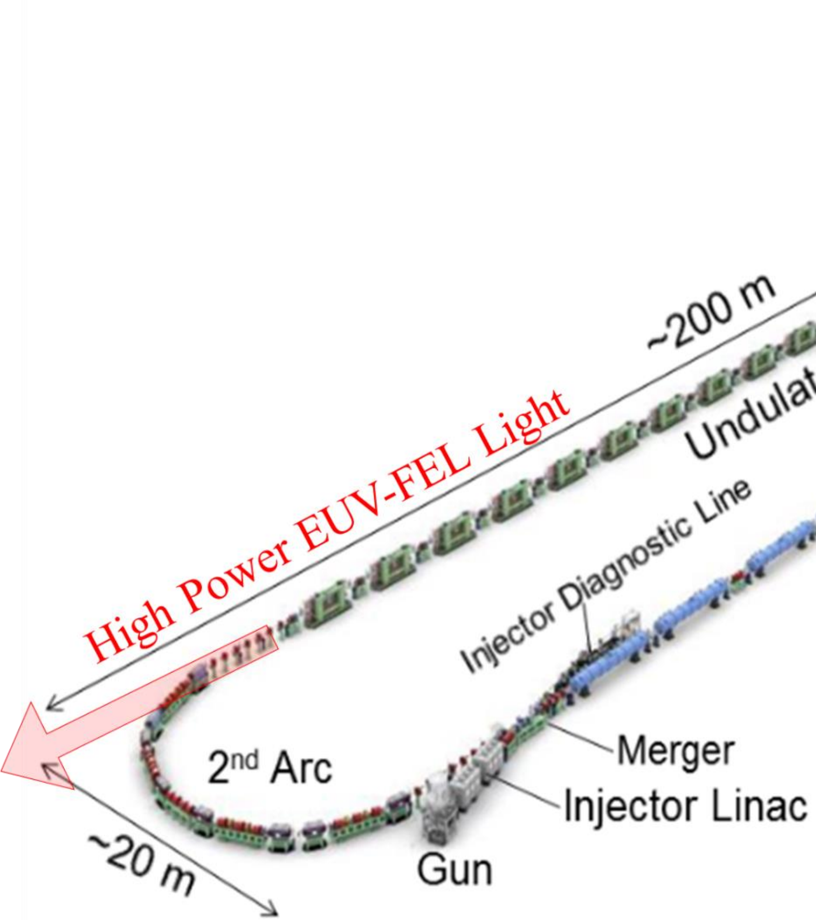
(3) Bunch compression



Coherent radiation spectrum up to THz
by bunch compression in 1st arc

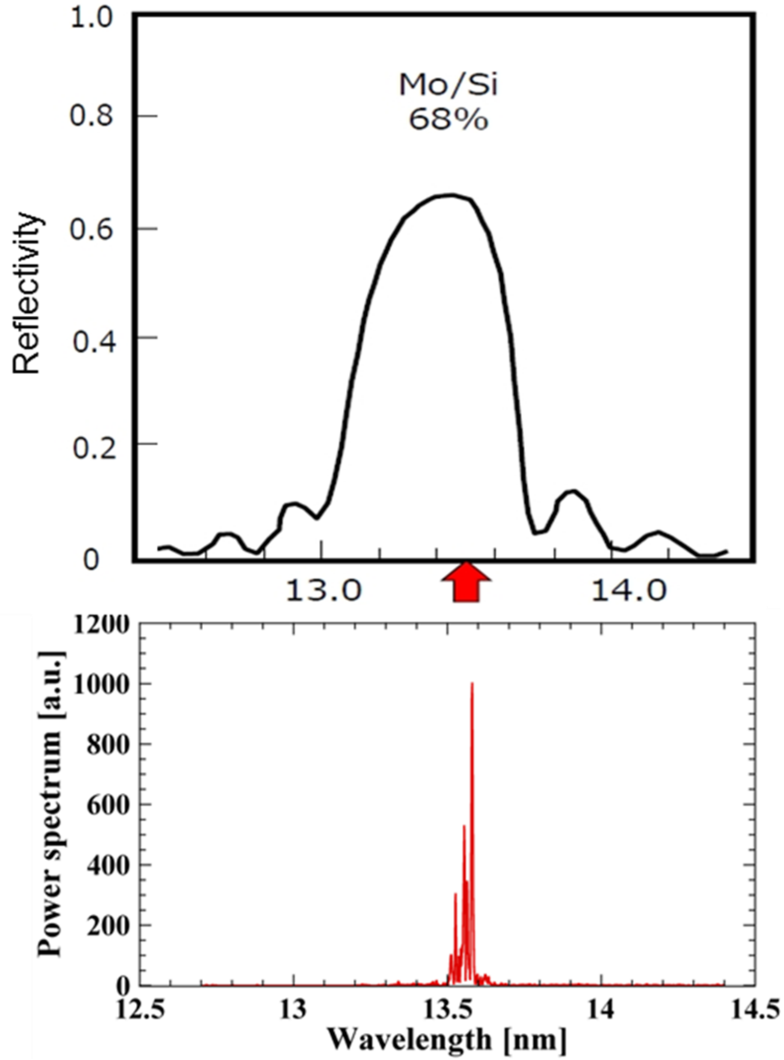
After the presentation at OSA workshop in Hiroshima (27-28/Oct.2016) presented by Prof. N. Nakamura

Prototype design of the EUV-FEL



Items	Achieved values in cERL	Design Values at the EUV-FEL
Energy for injector (MeV)	2.9-6	10.5
Energy of Accelerator(MeV)	20	800
Charge /bunch (pC)	0.7-5	60
Repetition rate (MHz)	162.5-1300	162.5
Average Current (mA)	1.0	9.75
Emitance for electron beam (mm mrad)	0.3-1	0.6
Gradient of the accelerated energy (MV/m)	8.6	12.5
Wavelength of EUV-FEL (nm)	/	13.5
Average power of EUV-FEL (kW)	/	Higher than 10 kW

Reflectivity of Multi-layer-mirror and Simulated Spectrum of the EUV-FEL light



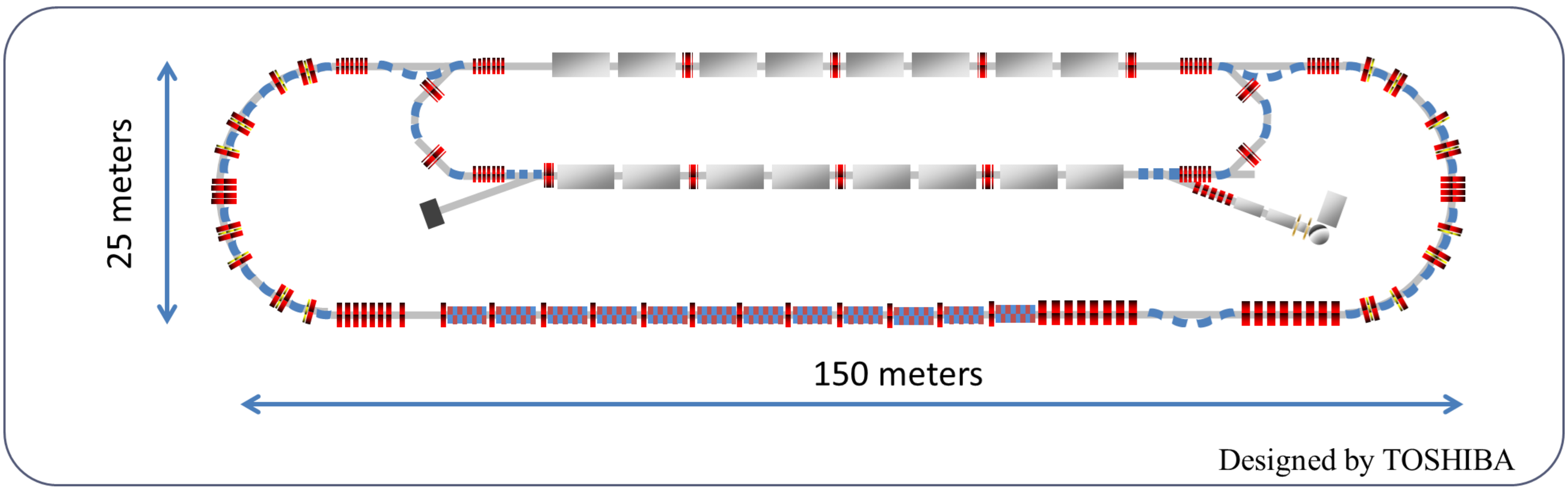
Further development for HVM light source

The much smaller EUV-FEL light source is required to install in Fab.

- Double loop scheme as shown in the figure below.
- Higher field gradient of the super conducting cavity (SC)

(Power consumption of the cryogenic systems) ∝ (field gradient)^2/Q

It is important to develop much higher Q materials for SC.



http://accelconf.web.cern.ch/AccelConf/SRF2015/

SRF2015 - Proceedings
Whistler, BC, Canada

Table of Sessions

MOBA — Fundamentals I - High-Q (14-Sep-15 10:40—12:50)

Chair: C.E. Reece, JLab, Newport News, Virginia, USA

Paper	Title	P
~~MOBA01~~	**SRF Linac for LCLS-II: Design Approaches, R&D and First Test Results**	

- **M.C. Ross**
  SLAC, Menlo Park, California, USA

This talk will describe the LCLS-II SRF linac stressing the challenges inherent in the technical specifications, the design approaches and the R&D program. Recent progress will be reported.

Slides MOBA01 [7.089 MB]

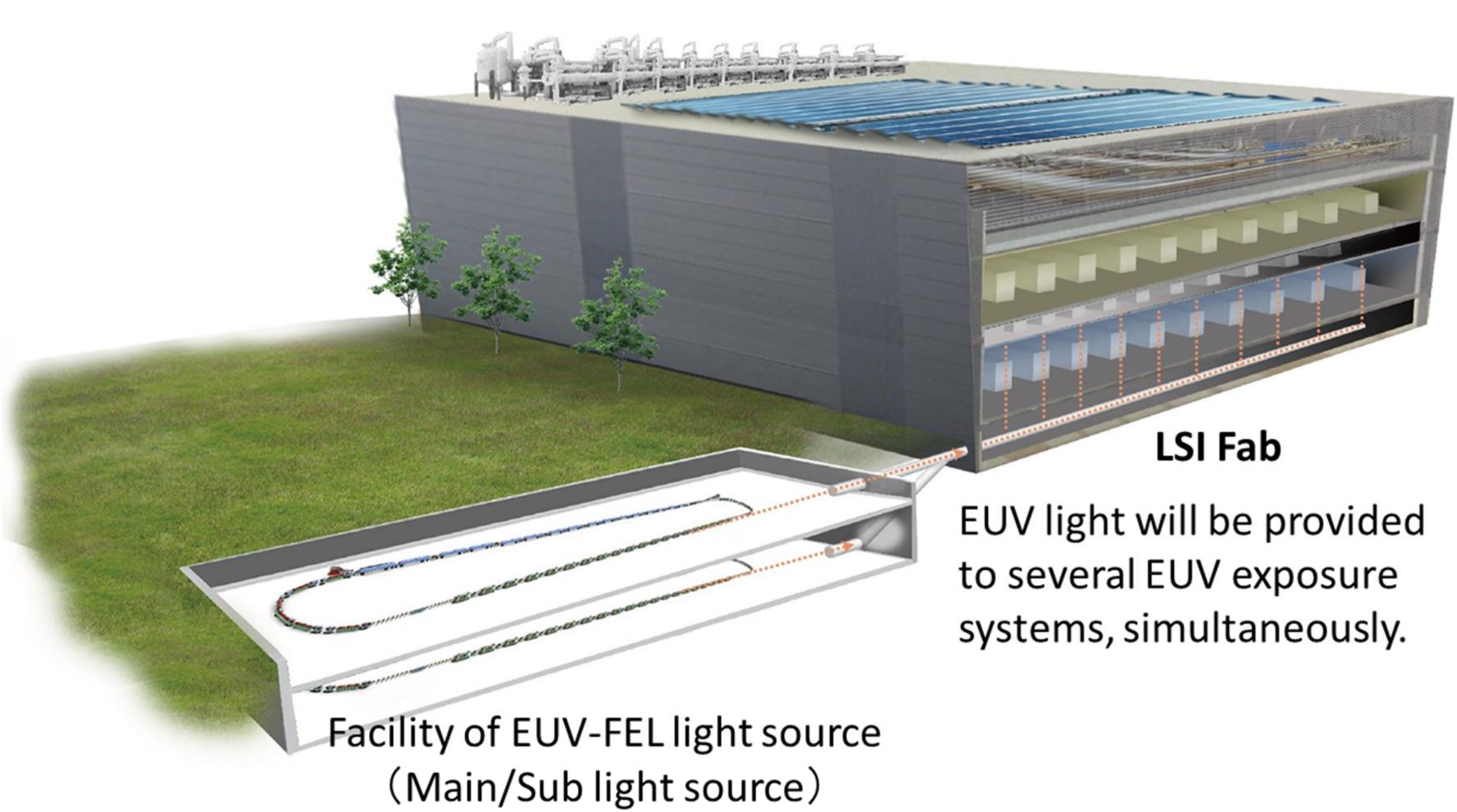
Export • reference for this paper to ※ *BibTeX*, ※ *LaTeX*, ※ *Text*, ※ *RIS/RefMan*, ※ *EndNote (xml)*

Paper	Title
~~MOBA02~~	**Efficient Magnetic Flux Expulsion During Cooldown**

- **A. Romanenko**
  Fermilab, Batavia, Illinois, USA

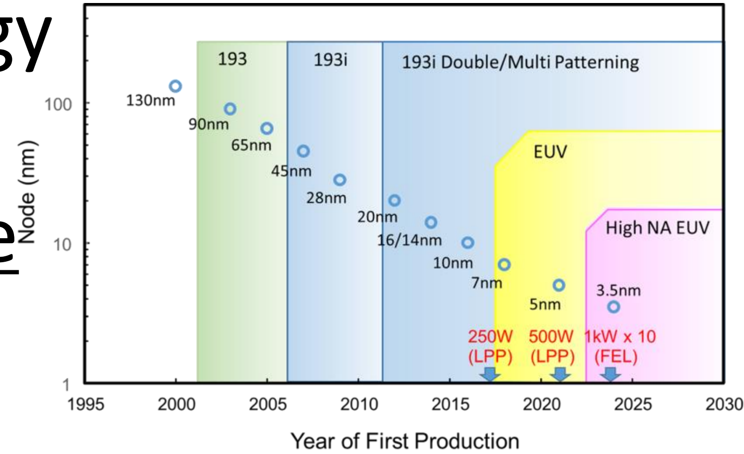
The talk will report recent experimental results and theoretical understanding of the magnetic flux expulsion during cooldown provided by large thermal gradients. The complete expulsion of the magnetic flux can lead to record-high Qs at accelerating gradients of ~20 MV/m. High Qs were achieved in ambient magnetic fields up to 190 mG. These findings open up a way to ultra-high quality factors at low temperatures and show an alternative to the sophisticated magnetic shielding implemented in modern superconducting accelerators.

Expected image of LSI Fab using EUV-FEL light source



Summary (1)

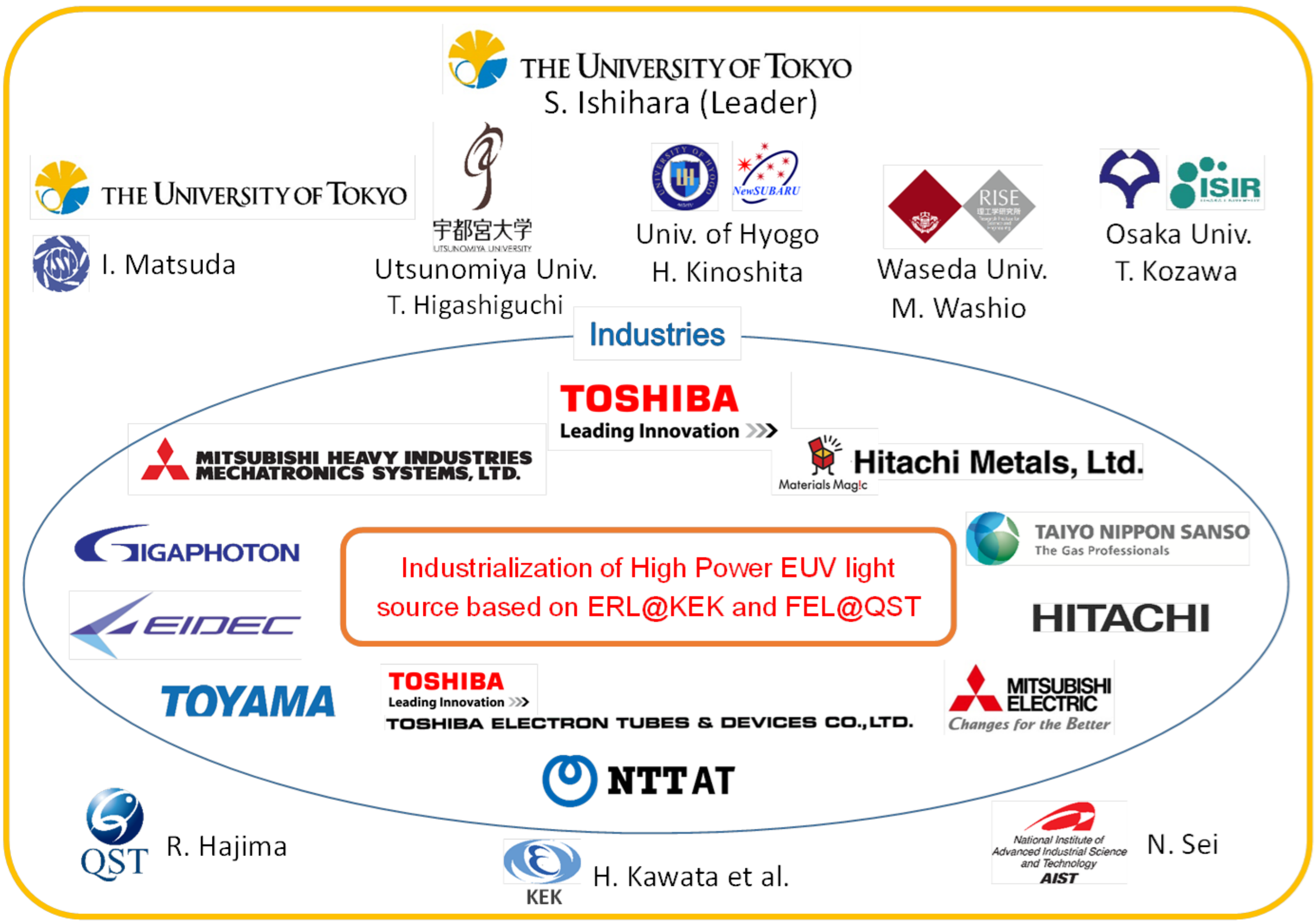
- In order to keep the technology node trend of Logic LSI , it is important <u>to push forward the construction of the prototype EUV-FEL light.</u>



- It is important to develop the light source and the related lithography integration should be done simultaneously in order to minimize the development resources and time.
- <u>To this end, source group, tool and material venders, and end users should have collaborative works from the early stage.</u>

Summary (2)

- At the beginning of the collaboration, the “EUV-FEL Light Source Study Group for Industrialization” has been established since last year (2015).



We will organize one-day workshop for EUV-FEL with source group, tool and material venders, and end users.

Date: 13/ Dec. /2016 10:00-17:00
Site: Akihabara UDX 4F NEXT-1, Tokyo
Registration fee: Free
URL: http://pfwww.kek.jp/PEARL/EUV-FEL_Workshop/

Thank you for your attention!